Time and Cost Optimization Techniques in Construction Project Management

(based on the critical path method (CPM))

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Introduction

In the field of Construction, every project is having planned budget and planned schedule. The budget is a term that means the measure of the cost that the project will consume in order for the final deliverable to be finished. The important objective of every project is to complete the scope of work on time, within the budget and the quality.

Reducing both construction projects' cost and time is critical in today's market-driven economy. This relationship between construction projects' time and cost is called trade-off decisions,

Time and cost trade off are the two important factors in every construction project which are crucial in achieving the project objectives. There is always a relationship between time and cost. Optimizing the time & cost is necessary in order to find out the optimum project duration corresponding to the minimum total cost.

Over the last several years, variety of methods for time and cost optimization was developed with the objective of minimizing the project cost and duration. However, existing methods ignored the effect of total float consumption resulting from decrease in duration with an increased in cost. there is a necessity to establish a new technique for a time cost trade off that can provide optimum time and cost value for a project taking into consideration the effect of total float consumption.

In this study an attempt is made based on the cpm method to find the planning which is applied to the practical project example related to construction of culvert in order to find out the optimum time and cost value.

What Is the Critical Path?

In project management, the critical path is the longest sequence of tasks that must be completed to successfully conclude a project, from start to finish. The tasks on the critical path are known as critical activities because if they're delayed, the whole project will be delayed. By identifying the critical path, you can determine the total duration of a project.

Calculating the critical path is key during the planning phase because the critical path identifies important deadlines and the activities which must be completed on time. Once a critical path is determined, you'll have a clear picture of the project's actual schedule.

To find this, project managers use the critical path method (CPM) algorithm to define the least amount of time necessary to complete each task with the least amount of slack.

What is the Critical Path Method in Project Management?

The critical path method (CPM), is a scheduling procedure that uses a network diagram to depict a project and the sequences of tasks required to complete it, which are known as paths. Once the paths are defined, the duration of each path is calculated by an algorithm to identify the critical path, which determines the total duration of the project.

The critical path method (CPM) is used in project management to create project schedules and helps project managers create a timeline for the project. The critical path method includes:

- Identifying every task necessary to complete the project and the dependencies between them
- Estimating the duration of the project tasks
- Calculating the critical path based on the tasks' duration and dependencies to identify the critical activities
- Focusing on planning, scheduling and controlling critical activities
- Setting project milestones and deliverables
- Setting stakeholder expectations related to deadlines

After making these considerations, you gain insight into which activities must be prioritized. Then, you can allocate the necessary resources to get these important tasks done. Tasks you discover that aren't on the critical path are of a lesser priority in your project plan, and can be delayed if they're causing the project team to become overallocated.

When you're analyzing the critical path, you're looking closely at the time it will take to complete each task, taking into account the task dependencies and how they'll impact your schedule. It's a technique to find the most realistic project deadline. It can also help during the project as a metric to **track your progress**.

Critical Path – Definition of Terms

To properly understand the concept of critical path, you first need to understand the various terms used in this method.

Earliest start time (ES): This is simply the earliest time that a task can be started in your project. You cannot determine this without first knowing if there are any preceding tasks, or figuring out other constraints that might impact the start of this task.

Latest start time (LS): This is the very last minute in which you can start a task before it threatens to upset your project schedule. And you need to calculate what the latest finish time is for the same reason. By having a clear picture of this timeframe, you can better schedule the project to meet its deadline.

Earliest finish time (EF): The earliest an activity can be completed, based on its duration and its earliest start time.

Latest finish time (LF): The latest an activity can be completed, based on its duration and its latest start time.

Float. Also known as **slack**, float is a term that describes how long you can delay a task before it impacts the planned schedule and threatens the project's deadline. The tasks on the critical path have zero float. If an activity has a float greater than zero, it means it can be delayed without affecting the project completion time.

How to Calculate the Critical Path

Now that you know the key definitions of CPM, here are the steps to calculate the critical path in project management:

1. **Collect Activities:** Use a work breakdown structure to collect all the project activities that lead to the final deliverable.
2. **Identify Dependencies:** Figure out which tasks are dependent on other tasks before they can begin.
3. **Create a Network Diagram:** A critical path analysis chart, or network diagram, depicts the order of activities.
4. **Estimate Timeline:** Determine the duration of each activity.
5. **Use the Critical Path Algorithm:** The algorithm has two parts; a forward pass and a backwards pass.
6. **Forward Pass:** Use the network diagram and the duration of each activity to determine their earliest start (ES) and earliest finish (EF). The ES of an activity is equal to the EF of its predecessor, and its EF is determined by the formula EF = ES + t (t is the activity duration). The EF of the last activity identifies the expected time required to complete the entire project.
7. **Backward Pass:** Begins by assigning the last activity's earliest finish as its latest finish. Then the formula to find the LS is LS = LF – t (t is the activity duration). For the

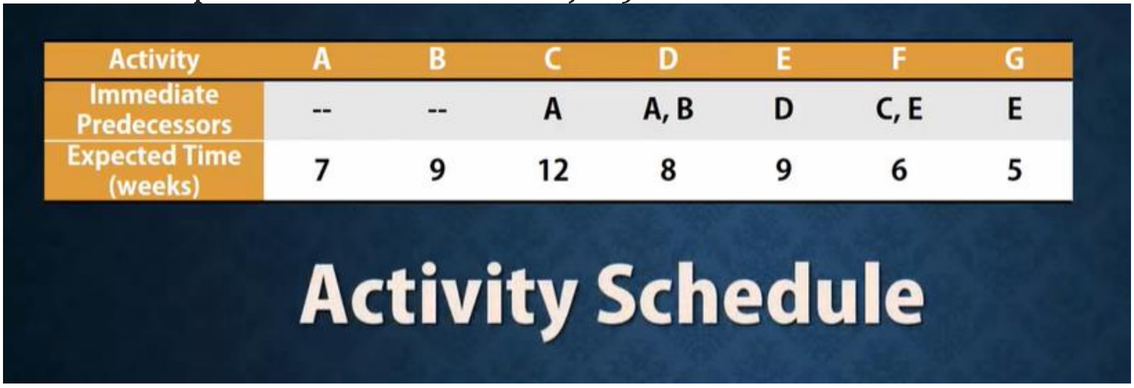
previous activities, the LF is the smallest of the start times for the activity that immediately follows.

8. **Identify the Float of Each Activity:** The float is the length of time an activity can be delayed without increasing the total project completion time. Since the critical path has no float, the float formula reveals the critical path: Float = LS – ES
9. **Identify the Critical Path:** The activities with 0 float make up the critical path.

These steps determine what tasks are critical and which can float, meaning they can be delayed without negatively impacting the project by making it longer .Now you have the information you need to plan the schedule more accurately and have more of a guarantee you'll meet your project deadline.

APPLICATION: Building a House

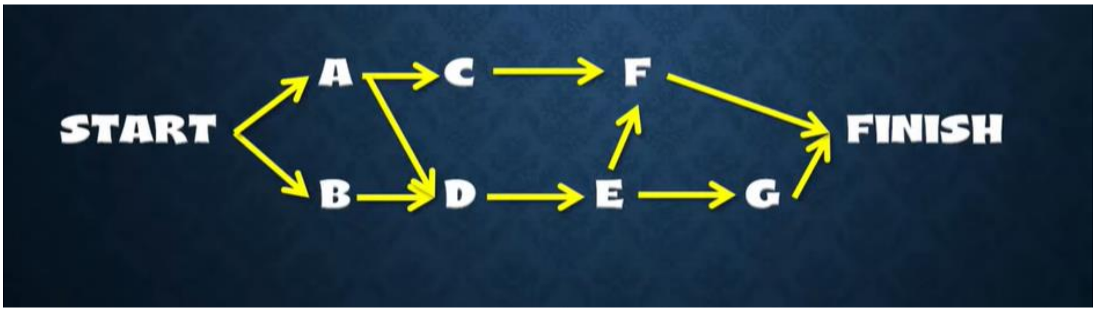
A simple and familiar example should help to clarify the notion of critical path scheduling and the process of constructing a graph. The project of building a house is readily analyzed by the CPM technique and is typical of a large class of similar applications. While a contractor might want a more detailed analysis, we will be satisfied here with the list of major jobs (together with the estimated time and the immediate predecessors for each job) shown in Exhibit I.



Activity	A	B	C	D	E	F	G
Immediate Predecessors	--	--	A	A, B	D	C, E	E
Expected Time (weeks)	7	9	12	8	9	6	5

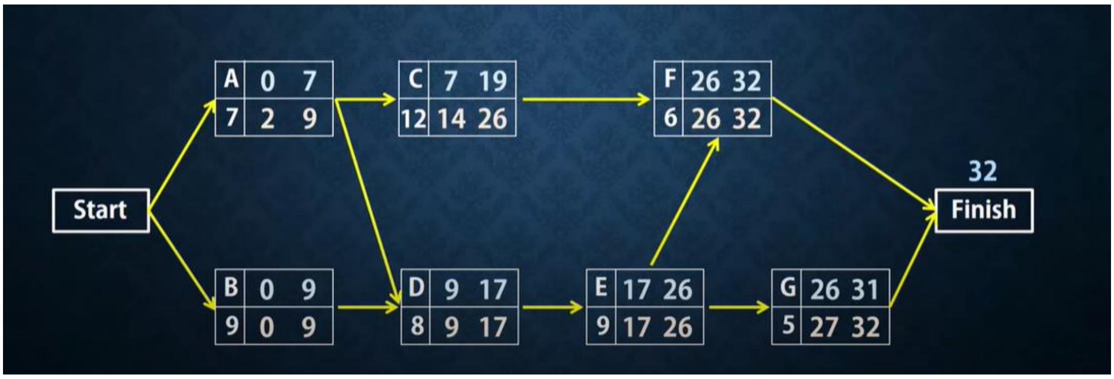
Activity Schedule

To determine the critical path we gonna follow this step:

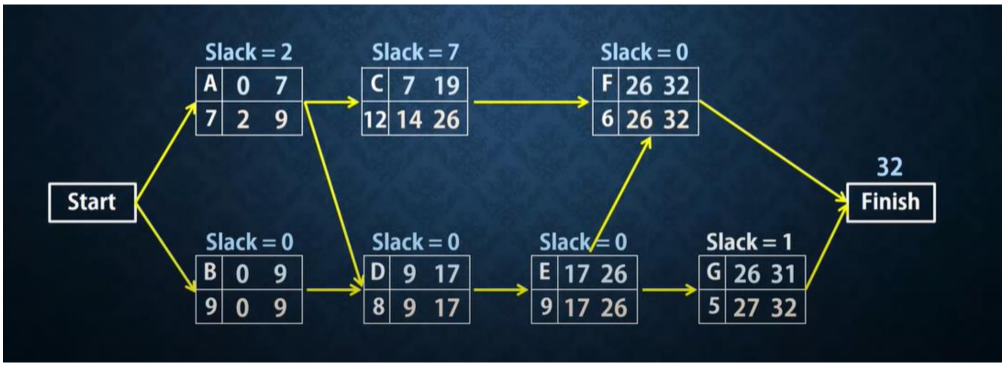


1. Construct a project network
2. perform forward and backward passes IN ORDER TO determine project completion time BY expressing this table of every activity

Activity name	Earliest start	Earliest finish
Activity time	Latest start	Latest finish

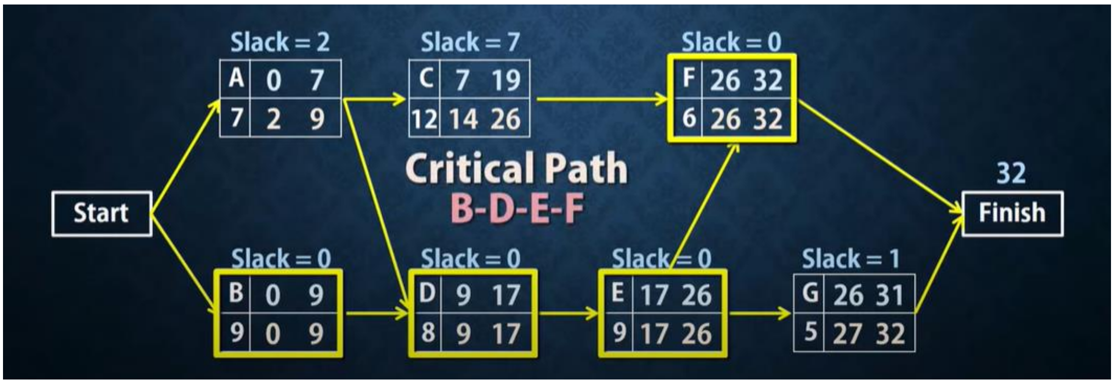


3. calculate slack values :slack= LS-ES=LF-EF



4. State the critical path:

   The critical activity are the one have slack =0 and form the critical path



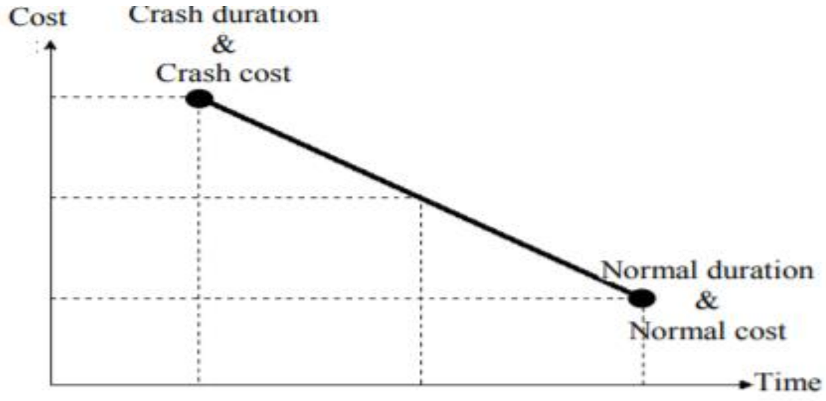
Time and cost trade off

Time-cost trade-off, in fact, is an important management tool for overcoming one of the critical path method limitations of being unable to bring the project schedule to a specified duration.

Activity Time-Cost Relationship

In general, there is a trade-off between the time and the direct cost to complete an activity; the less expensive the resources, the larger duration they take to complete an activity. Shortening the duration on an activity will normally increase its direct cost which comprises: the cost of labor, equipment, and material. It should never be assumed that the quantity of resources deployed and the task duration are inversely related. Thus one should never automatically assume that the work that can be done by one man in 16 weeks can actually be done by 16 men in one week.

A simple representation of the possible relationship between the duration of an activity and its direct costs appears in Figure 8.1. Considering only this activity in isolation and without reference to the project completion deadline, a manager would choose a duration which implies minimum direct cost, called the normal duration. At the other extreme, a manager might choose to complete the activity in the minimum possible time, called crashed duration, but at a maximum cost



e 8.1: Illustration of linear time/cost trade-off for an activity

The linear relationship shown in the Figure above between these two points implies that any intermediate duration could also be chosen. It is possible that some intermediate point may represent the ideal or optimal trade-off between time and cost for this activity. The slope of the line connecting the normal point (lower point) and the crash point (upper point) is called the cost slope of the activity. The slope of this line can be calculated mathematically by knowing the coordinates of the normal and crash points. Cost slope = crash cost – normal cost / normal duration – crash duration

We wants to investigate how much extra it would cost to reduce the expected project duration down (the deadline for the company earning a bonus of $150,000 for early completion). We remember that CPM provides an excellent procedure for using linear programming to investigate such time-cost trade-offs, so based on cpm we are going to see this deterministic approach

Deterministic approach

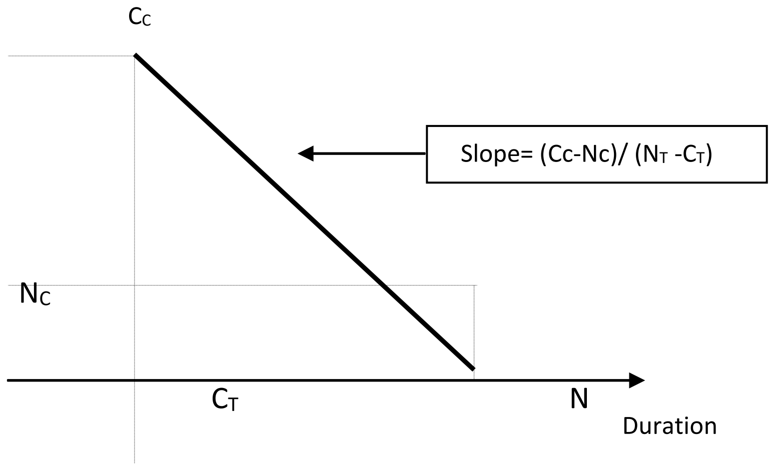
The deterministic approach is based on critical path method and has been the most widely used method in planning and controlling of the construction projects. The important objective of the critical path method implementation was to determine how best to reduce the time required to perform routine and repetitive tasks that are needed to support an organization.

Various Terms used in Time Cost Optimization

1) Normal Cost: It is the lowest cost of completing an activity in minimum time employing normal means that is not using overtime or special resources.
2) Normal Time: It is minimum time required to achieve the normal cost.
3) Crash Cost: It is a least cost of completing an activity by employing all possible means like overtime, additional machinery and proper materials.
4) Crash Time: It is an absolute minimum time associated with the crash cost.

5) Critical Path: It is the sequence of project network terminal elements with the longest overall duration, determining the shortest time to complete the project.

Following Steps are carried out while performing the time and cost optimization.



The procedure for shortening project duration can be summarized in the following steps:

1. Draw the project network.

2. Perform CPM calculations and identify the critical path, use normal durations and costs for all activities

. 3. Compute the cost slope for each activity from the following equation: cost slope = crash cost – normal cost / normal duration – crash duration

4. Start by shortening the activity duration on the critical path which has the least cost slope and not been shortened to its crash duration.

5. Reduce the duration of the critical activities with least cost slope until its crash duration is reached or until the critical path changes.

6. When multiple critical paths are involved, the activity(ies) to shorten is determined by comparing the cost slope of the activity which lies on all critical paths (if any), with the sum of cost slope for a group of activities, each one of them lies on one of the critical paths.

7. Having shortened a critical path, you should adjust activities timings, and floats.

8. The cost increase due to activity shortening is calculated as the cost slope multiplied by the time of time units shortened.

9. Continue until no further shortening is possible, and then the crash point is reached.

10. The results may be represented graphically by plotting project completion time against cumulative cost increase. This is the project direct-cost / time relationship. By adding the project indirect cost to this curve to obtain the project time / cost curve. This curve gives the optimum duration and the corresponding minimum cost

Cost Calculations

The cost of carrying out a project can be readily calculated from the job data if the cost of doing each job is included in the data. If jobs are done by crews, and the speed with which the job is done depends on the crew size, then it is possible to shorten or lengthen the project time by adding or removing men from crews. Other means for compressing job times might also be found; but any speedup is likely to carry a price tag. Suppose that we assign to each job a **"normal time**" and a "**crash time**" and also calculate the associated costs necessary to carry the job in each time. If we want to shorten the project, we can assign some of the critical jobs to their crash time, and compute the corresponding direct cost. In this way it is possible to calculate the cost of completing the project in various total times, with the direct costs increasing as the over-all time decreases.

Added to direct costs are certain overhead expenses which are usually allocated on the basis of total project time. Fixed costs per project thus decrease as project time is shortened. In ordinary circumstances a combination of fixed and direct costs as a function of total project time would probably fall into the pattern shown in Exhibit below. The minimum total cost (point A) would likely fall to the left of the minimum point on the direct cost curve (point B) indicating that the optimum project time is somewhat shorter than an analysis of direct costs only would indicate.

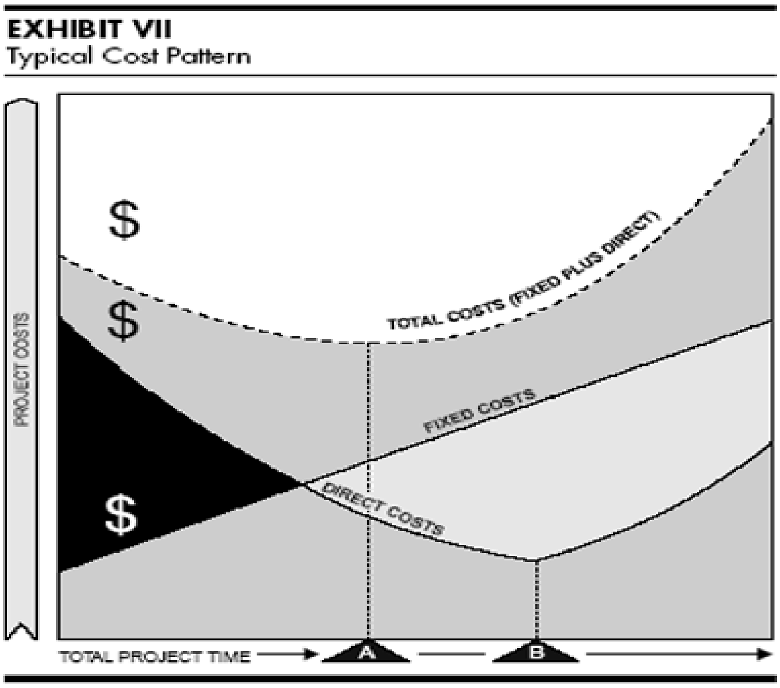


Exhibit VII Typical Cost Pattern

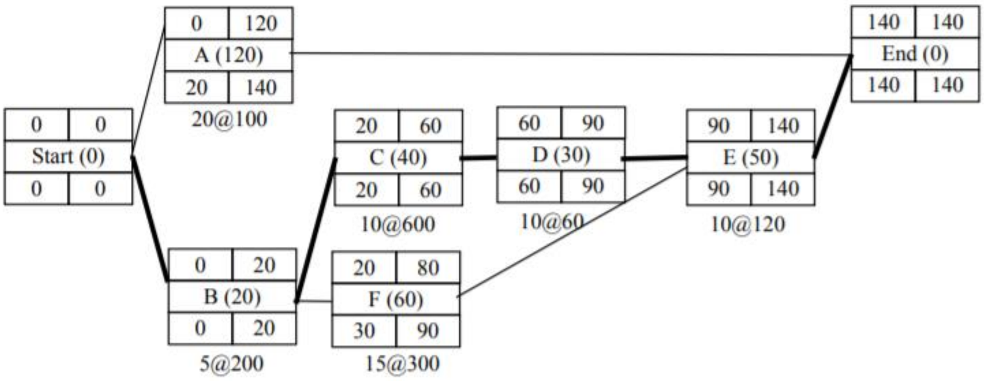
Application

Assume the following project data given in Table . It is required to crash the project duration from its original duration to a final duration of 110 days. Assume daily indirect cost of LE 100.

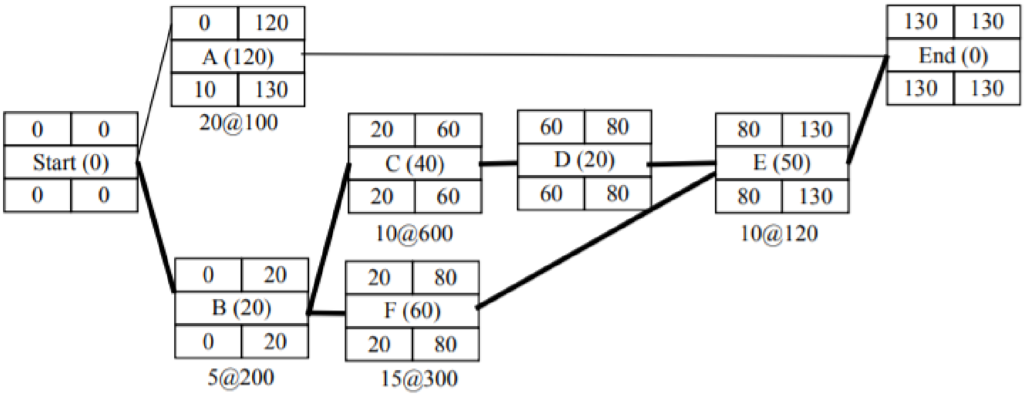
Activity	Preceded by	Normal		Crash	
		Duration (day)	Cost (LE)	Duration (day)	Cost (LE)
A	-	120	12000	100	14000
B	-	20	1800	15	2800
C	B	40	16000	30	22000
D	C	30	1400	20	2000
E	D, F	50	3600	40	4800
F	B	60	13500	45	18000

Solution

The cost slope of each activity is calculated. Both the crushability and the cost slope are shown beneath each activity in the precedence diagram. The critical path is B-C-D-E and the project duration in 140 days. Project total normal direct cost = sum of normal direct costs of all activities = LE 48300.



1. The activity on the critical path with the lowest cost slope is of activity “D”, this activity can be crashed by 10 days. Then adjust timing of the activities.

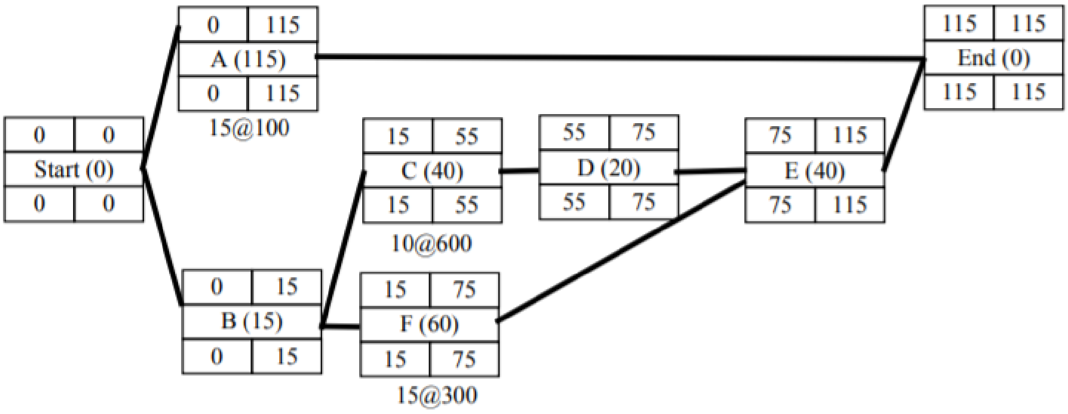


A new critical path will be formed, B-F-E.

New Project duration is 130 days.

The project direct cost is increased by 10 x 60 = LE 600. Project direct cost = 48300 + 600 = LE 48900

2. At this step activity “E” will be crashed, as this activity lies on both critical paths. Activity “E” will be shortened by 10 days.



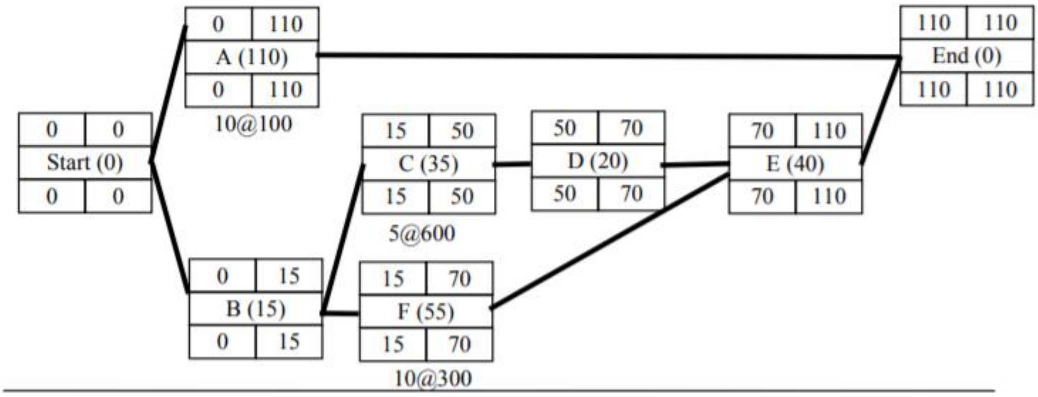
Accordingly, all activities will b turn to critical activities.

New Project duration is 120 days.

The project direct cost is increased by 10 x 120 = LE 1200.

Project direct cost = 48900 + 1200 = LE 50100

3. In this step, it is difficult to decrease one activity's duration and achieve decreasing in the project duration. So, either to crash an activity on all critical paths (if any), otherwise, choose several activities on different critical paths. As shown, activities "A" and "B" can be crashed together which have the least cost slope (100 + 200). Then, crash activities "A" and "B" by 5 days.

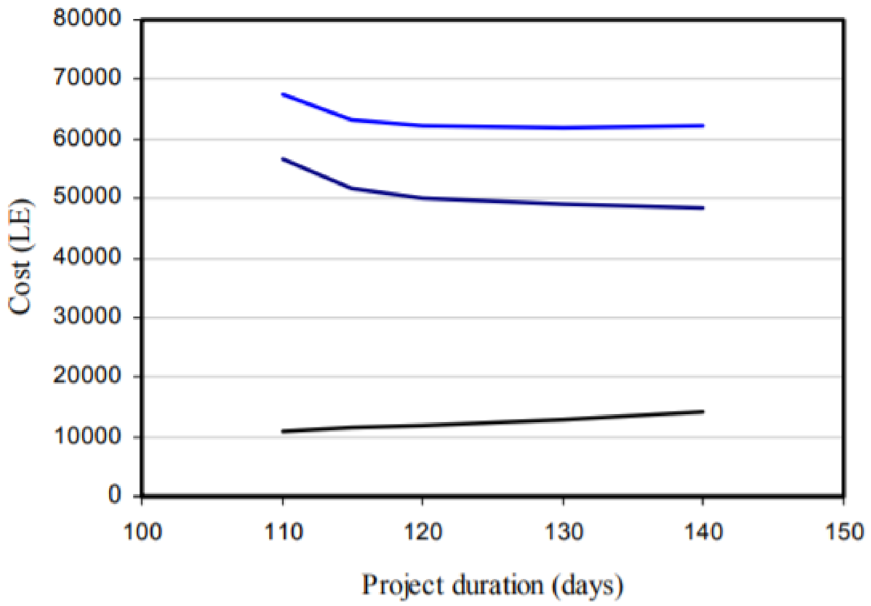


New Project duration is 115 days.

The project direct cost is increased by 5 x (100 + 200) = LE 1500.

Project direct cost = 50100 + 1500 = LE 51600

4. In this final step, it is required to decrease the duration of an activity from each path. The duration of activity "A" will be crashed to 110 days, "C" to 35 days, and "F" to 55 days. Thus, achieving decreasing project duration to 110 days. Also, increase in the project direct cost by 5 x (100 + 600 + 300) = LE 5000



Duration (days)	Direct cost (LE)	Indirect cost (LE)	Total cost (LE)
140	48300	14000	62300
130	48900	13000	61900
120	50100	12000	62100
115	51600	11500	63100
110	56600	11000	67600

APPLICATION IN MOROCO

In morocco ; as a country in development a lot of project start in our 20 century and the need to optimize cost and make the deadline date early are problem that face the public works company and the engineer so to tackle this problem they came to use this method in order to optimist the time and cost by using software What's Best Solver ® Version: 11.0 . it is added into excel and supports a variety of optimization models such as linear, integer, quadratic and nonlinear models within an excel spreadsheet. This software is useful in determining an optimal solution containing 150 constraints, 300 variables and 30 integers.

So with the help of this method and others tools the company will save money and our country will start quick development especially in the south of morocco where we need to work more hard and quick in order to make morocco great.

So finally , as a goal for me to be one day a successful project manager (is a person who has the overall responsibility for the successful initiation, planning, design, execution, monitoring, controlling and closure of a project.) this research have helped me more to understand the difficulty that face a project manager and the pressure that he have to deal with.

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